IMPACTS OF LOW AND HIGH WATER LEVELS ON INLAND WATERWAY TRANSPORT

FINAL VERSION

LITERATURE REVIEW FOR 'KENNIS VOOR KLIMAAT'

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Contents

1 Introduction

Climate change is likely to affect many sectors in the economy. This study addresses the impact of climate change on one specific type of transport in the total transport sector: inland waterway transport. The aim of this study is to make an inventory of the (scientific) literature that addresses the impact of climate change, on specific characteristics of this transport mode namely: transport prices, transport reliability and its modal share.

This literature survey is the first research step within the research theme “water and transport” of the “Knowledge for Climate, Hotspot Rotterdam” research project, and it contributes to the impact study phase of the project. In the next phase, in which we explore adaptation measures, the knowledge from the impact study phase can be used to examine the feasibility of these measures.

The knowledge we obtain in the current report is relevant since costs and reliability determine the competitive position of inland waterway transport to a large extent. Climate change is likely to affect these determinants of mode choice negatively, possibly resulting in a loss of freight by inland waterways to competing modes. Consequently, the competitive position of sea-ports that (heavily) rely on inland waterway transport may worsen.

The remainder of this report is organized as follows. In Section 2 the topics climate change and inland waterway transport (in relation to the Port of Rotterdam) will be introduced. Next, we provide an overview of the literature on the effect of climate change on inland waterway transport costs (Section 3), inland waterway transport reliability (Section 4), and modal split (Section 5). Finally, Section 6 concludes.

This literature review is carried out in the framework of the Dutch National Research Programme “Knowledge for Climate, Hotspot Rotterdam”. Its aim is to contribute to the knowledge of the impact of climate change on the region of Rotterdam and to examine how the impact can be reduced in order to make the Rotterdam area ‘climate proof’.

2 Climate change and inland waterway transport

2.1 Climate change

(IPCC, 2007) expects that the cause of most of the observed increase in global average temperatures since the mid-20th century is due to the observed increases in anthropogenic greenhouse gas concentrations in the atmosphere. These concentrations of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) have increased markedly as a result of human activities since 1750. Carbon dioxide is the most important anthropogenic greenhouse gas. Its annual emissions grew by about 80 per cent between 1970 and 2004. Continued greenhouse gas emissions at or above current rates will cause further warming and induce many changes in the global climate system during the 21th century (IPCC, 2007). Many studies have been occupied with estimations of this future climate change.

An obvious problem with these studies, however, is that we do not know exactly how the climate will be in the future. A means of dealing with this uncertainty is the construction of climate scenarios. For the Netherlands, the Royal Dutch Meteorological Institute (KNMI) has developed a set of climate scenarios which focus on changes for 2050. The main dimensions underlying the scenarios are described in Table 1 (KNMI, 2006).

Table 1: Values for the steering parameters of the KNMI'06 climate scenarios for 2050 relative to 1990.

Scenario	**Global temperature increase in 2050**	**Change of atmospheric circulation**
G	+1°C	weak
G+	+1°C	strong
W	+2°C	weak
W+	+2°C	strong

Source: (KNMI, 2006).

In these climate scenarios, two main uncertainties are considered: the level of global temperature increase and the extent of change of atmospheric circulation (wind direction). A strong change of circulation induces warmer and moister winter seasons and drier and warmer summertime situations than a weak circulation change. The combinations of global temperature increase and change of circulation result in four scenarios. The scenario label “G” stands for “Moderate”, while “W” stand for “Warm”. The “+” indicates that these scenarios include a strong change of circulation. Although the climate scenarios have been specifically constructed for the Netherlands, they are based on the outcomes of several international climate models for Western Europe. Therefore, they give a good indication of possible climate conditions in this area. According to the climate scenarios, the changing climate will result in milder winters and warmer summers. Furthermore, it will rain more often in wintertime with more heavy showers (higher extremes). Also during summertime more heavy showers will occur but the number of days with rain will decrease. This will result in longer periods of drought in summer. The wind direction plays an essential role for the extent to which the climate will change: in the + scenarios the changes will be most severe.

2.2 The Port of Rotterdam and inland waterway transport

The Port of Rotterdam is a hub of international goods flows, while at the same time an industrial complex of global stature. The port is the gateway to a European market of more than 500 million consumers. With an annual throughput of more than 400 million tonnes of goods, Rotterdam is by far the biggest seaport in Europe (Port of Rotterdam, 2009).

Because of the excellent waterway connections to the hinterland, inland waterway freight transport to and from the Port of Rotterdam has a significant share in the hinterland modal split. Table 2 shows that, ignoring transport by pipeline and short sea shipping, inland waterway transport accounts for about 80% of all non-domestic hinterland transport, measured in tonnes.[1]

[1] As domestic hinterland transport takes place on relatively short distances, the modal share for inland waterways will most probably be lower when domestic haul is included.

Note that the outgoing volume of international oriented inland waterway transport from the port is about three times larger than the incoming volume in the port indicating that the port of Rotterdam is an import oriented port.

Table 2: Outgoing and incoming goods (x 1000 tonnes) for the Port of Rotterdam in 2006 (domestic haul excluded)

	Inland waterways	**Road***	**Rail**	**Total**
Outgoing	81,997	8,251	13,164	103,412
Incoming	25,359	4,793	2,389	32,541

*Note : only Dutch trucks

Source: (Port of Rotterdam, 2009).

Table 3 : Container modal split for load centres in the Le Havre-Hamburg range (in %, excluding sea-sea transshipment)[2]

Port	**Rail**	**Road**	**Inland waterways**
Rotterdam	10.0	50.0	40.0
Antwerp	9.5	59.5	31.0
Le Havre	12.4	82.8	4.8
Zeebrugge	40.2	55.1	4.7
Dunkirk	20.5	76.7	2.7
Hamburg	28.7	69.8	1.7
Bremerhaven	30.6	67.3	2.0

Source: (Notteboom, 2007).

Comparing the container modal split of the sea-ports in the Hamburg-Le Havre range, Table 3 shows that Rotterdam relies most heavily on inland waterway transport. Also, for transportation to and from the port of Antwerp a significant share is taken by inland waterways. In the remaining sea-ports inland waterway transport is of minor importance. This implies, assuming

[2] The modal split for bulk cargo in the sea-ports shows a similar pattern as the one for containers.

that climate change will affect inland waterway transport negatively, that the port of Rotterdam will suffer more from these negative effects than competing sea-ports.

The port of Rotterdam is located in the Rhine-Meuse estuary. The river Rhine is the most important trade waterway in Europe as it connects large economic core areas within and between the Netherlands and Germany. In 2006 about 320 million tonnes were transported on this corridor. As this river route developed long ago, the increase in the volume transported over time is relatively slow, but structural. It reflects the development of an industrial area that has existed for a long time (CCNR and European Commission, 2007). The river Meuse is much smaller than the river Rhine, both, physically and its economic importance. An advantage of the Meuse is that this waterway is canalized so that also in dry periods the navigability can more or less be guaranteed.

2.3 Effect of climate change on inland waterway transport

As a result of climate change, inland waterway transport may experience problems related to higher volatilities in water levels.

The river Rhine is a combined rain-snow river. As a result of climate change, it is expected that the Rhine will be more rain-oriented in the future. More specifically, it is expected that, in winter, precipitation will increase, and higher temperatures will cause a smaller proportion of precipitation to be stored in the form of snow in the Alps. As a result, in winter more precipitation will directly enter rivers, average and peak water levels will be higher, and the number of days with low water levels will decrease. In summer, besides a reduction in melt water contribution, there will be less precipitation and more evaporation due to higher temperatures. As a consequence, inland waterway vessels on the Rhine will experience lower water levels, as well as an increase in the number of days with low water levels in summer and autumn (Middelkoop et al., 2000; 2001). Low water levels imply restrictions on the load factor of inland ships. This suggests that the capacity of the inland waterway transport fleet is (severely) reduced in periods with low water levels, which has (economic) consequences.

As low water levels hardly occur during winter, the reduction of days with low water levels in winter will be small. However, an increase of days with high water levels in winter implies an increase in the number of days on which inland waterway transport is blocked for safety reasons.[3]

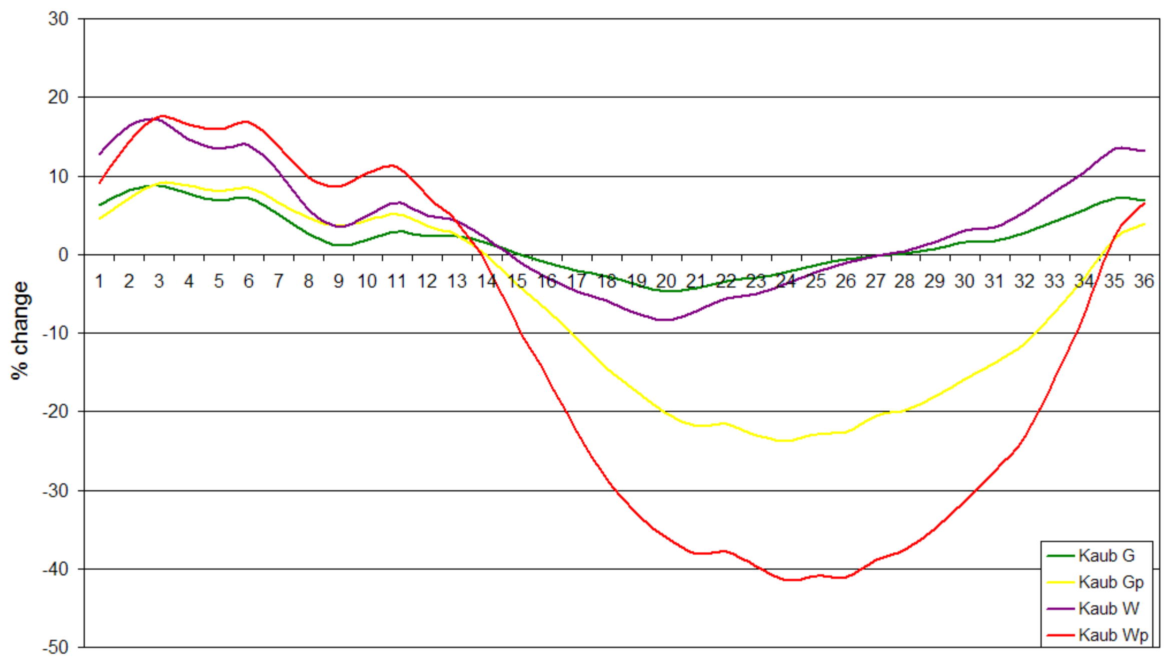

Figure 1: Change in discharge (in m^3/sec) of the Rhine during a year under the KNMI'06 climate scenarios at Kaub.

Source: te Linde, 2007.

Figure 1 illustrates what the effect of climate change on discharge of the river Rhine at the location Kaub (a small town which is located on the East bank of the Rhine in middle Germany) is expected to be under the four climate scenarios that were d7nescribed in Section 2.1.[4] On the horizontal axis, the time period of one year is divided into 36 periods of ten days. The vertical

[3] River dikes are heavily put to the test in periods of high water levels, and they may break as a result of the extra pressure inland waterway vessels impose on these dikes during periods with high water levels.

[4] Discharges in rivers (measured in m^3/sec.) can be converted to water levels (measured in centimeters) by means of the so called discharge rating curve. Formulas exist for this conversion for several locations at the Rhine. These formulas have to be updated now and then because of changes in the structure of the riverbed over time. Discharges and water levels at the location Kaub are especially important as it is here that water level restrictions are most limiting: they determine the load factor of virtually all inland ships that pass Kaub.

axis shows the expected percentage change in discharge compared with the average discharge between 1961 and 1995.

In the summer months June, July and August, there are only minor changes in the mean discharge in the G and W scenarios. However, the G+ and W+ scenarios (each with a strong change of atmospheric circulation), show a decrease in mean discharge of 22 – 42 per cent (Te Linde, 2007). A reduction in discharge may cause several problems. For example, inland ships may have to reduce their load factor resulting in higher unit transport prices. (Jonkeren *et al.*, 2009) compare the average annual number of days with water levels at Kaub that cause load factor restrictions for an inland ship of average size in the period 1987 – 1995 with the year 2050 under the four KNMI'06 climate scenarios (see Table 4).

Table 4: Effect of climate scenarios on the length of the low water period

Climate scenario	**Base period (1987 – 1995)**	**G (2050)**	**G+ (2050)**	**W (2050)**	**W+ (2050)**
Average annual number of days with load factor restrictions	103	99	140	95	182

Source: (Jonkeren *et al.*, 2009)

In Table 4, we observe that only in the G+ and W+ scenarios, the number of days with load factor restrictions increase considerably compared to a year under current climate conditions (base period). In addition to load factor restrictions, the reliability of inland waterway transport may be negatively affected as a result of low water levels. Lower load factors imply more traffic movements leading to longer (un)loading and waiting times in front of locks for carriers.

Focusing on high water levels, the mean rise in discharge in the winter months December, January and February varies from 8 per cent for the G scenario to 16 per cent for the W+ scenario (Te Linde, 2007). Interesting for the inland waterway transport sector however, is the frequency and length of high water level periods that lead to a blockage of inland waterway traffic under future climate change. Unfortunately, no data is available on this. As an alternative we present the history of inland waterway transport blockages on the Rhine since the year 2000 in Table 5. Except from the year 2002, blockages occurred not at all, or once a year. The length of a blockage is between one and four days. Clearly, a blockage on inland waterways negatively affects reliability and consequently may increase transport costs for shippers.

Table 5: Blockages of inland waterway transport in the Rhine as a result of high water levels

Date	Location	Length (in days)
23-03-2002	Bingen	3
04-11-2002	Maxau	4
14-01-2004	Maxau	2
16-01-2004	Koblenz	1
17-01-2004	Andernach	1
23-08-2005	Maxau	3
24-08-2005	Mainz	n.a.
10-03-2006	Maxau	3
09-08-2007	Maxau	3
23-04-2008	Maxau	1

Note: Koblenz and Mainz are located downstream of Maxau, Andernach is located downstream of Koblenz.

Source: (RWS-Infocentrum Binnenwateren, 2009)

This section has shown that low and high water levels result in restrictions on the load factor of inland ships and blockages on inland waterways, implying higher transport costs and a deterioration of transport reliability. Consequently, shippers may decide to use another transport mode, which means a loss of demand for inland waterway transport. In the remainder of this study, we will discuss the available literature on transport costs, reliability and modal share in the context of inland waterway transport and climate change.

3 Transport costs

In this section we will discuss the literature on water levels and inland waterway transport costs. Low water levels imply restrictions on the load factor of inland waterway vessels. As a consequence, the costs per tonne, and thus also the price per tonne transported will rise. Note that this effect of the water level on transport prices is only present when the water level drops below a certain threshold.

In an early study (Marchand *et al.*, 1988) use a hydrologic model to predict changes in water levels and water level variation due to climate change for the year 2035. By applying an extensive transport model they subsequently simulate the consequences of these changes for average annual shipping costs in the Great Lakes – St. Lawrence river system in Canada. They show that mean annual shipping costs from 1979 to 2035 may increase by 5% because of low water levels. Moreover, they find a large increase in the frequency of extreme costs. Results from this 1988 study may be criticized because climate change scenarios around that time were not as advanced as they are now.

In a recent study on the consequences of climate change for shipping in the Great Lakes river system, (Millerd, 2005) estimates that increases in average operating costs as a result of low water levels may indeed be substantially higher. Specifically, using climate change scenarios for 2030 and 2050 from the Canadian Centre for Climate Modelling and Analysis, he estimates that compared to 2001 the average operating costs in 2030 increase by 3–14% depending on the industrial sector, with an average of approximately 8%. Estimates for 2050 range from 6% to 22%, with an average of 13%.[5]

Results of a similar exercise for the Middle Mississippi River are reported in (Olsen *et al.*, 2005). They estimate losses in shipper savings, defined as the difference between costs of shipping and costs of the cheapest transport alternative, due to low water levels for the period 1933–2002. Losses over the entire period amount to $77 million per year on average. Because of wetter weather conditions the annual losses in the 1968–2002 period were substantially lower ($25 million). Subsequently they simulate the impact of climate change using synthetic water flows for 2100 from three GCM climate change scenarios. Since these scenarios produce very different estimates for future precipitation patterns and run-off, the results vary widely. In the first scenario the costs increase from $77 to $118 million per year, while in scenarios 2 and 3 the costs decrease to $10 and $24 million respectively.[6] The models furthermore differ with respect to the costs of high water levels, which may lead to temporary closure of the river system for freight transport. The pattern in the results is exactly opposite to the pattern found for low water levels. Costs for the 1933–2002 period amounted to $12 million per year. Costs for the first climate change scenario decrease to $1.5 million per year, while costs increase in scenarios 2 and 3 to $41 and $27 million.[7]

[5] See (Millerd, 1996) for an earlier assessment of the impact of water levels on operating costs of inland shipping in the Great Lakes area.

[6] Although at first sight these cost figures appear low in an absolute sense, note that this study deals with only a small part of the Mississippi related transport market.

[7] Lofgren et al. (2000) show that a positive effect of climate change may be a substantial reduction in ice cover on the Great Lakes. They do not assess the (potential) positive consequences for the commercial shipping sector.

Shifting our attention to Europe, (Nomden and W.van Deursen, 1999) examine the effect of climate change on inland waterway transport costs (and mode choice) by means of interviews and the inland waterway transport simulation model Ships@Risk.[8] This model calculates the daily transport capacity and daily transport costs, stock levels of the shipper and the number of used ships using input on ship types, the amount to be transported, the route, transport costs and hydrological data. Interviews with carriers were used to determine realistic input values for the Ships@Risk model. Based on the Ukhi climate scenario for 2050 (Hulme *et al.*, 1994), the model predicts for several carriers on the river Rhine that unit transport costs will increase by about 10 per cent.[9]

(Jonkeren *et al.*, 2007) analyze freight prices of approximately 2800 shipping trips on the river Rhine in the period January 2003 to June 2005. Approximately 70% of all inland waterway transport (in tonnes) in the EU is transported on the Rhine. Water levels are measured at Kaub, which at low water levels is the bottleneck for a substantial part of the Rhine market: the Kaub-related Rhine market.[10] Further, since inland waterway carriers that operate under long-term contracts do not report their trips, only transport enterprises that operate on the spot market are included in the dataset. Applying regression analysis to explain freight prices per tonne, the study clearly shows increasing freight prices at decreasing water levels. The authors find that for an average inland ship the transport price per tonne may increase with 74% in periods with very low water levels.[11] Additional analyses show that large ships receive higher transport prices than small ships in periods with low water levels. Another interesting result is that the elasticity of demand for inland waterway transport is found to be about -0.5, suggesting that demand for

[8] The effect on modal split will be addressed in section 5.

[9] For a carrier in the downstream part of the river Rhine the increase in transport costs was calculated to be lower (7.8 per cent) than for a carrier in the upstream part (12.3 per cent).

[10] About 300 million tonnes are transported on the Rhine each year, of which around 80 million tonnes pass by Kaub. The study therefore covers around 27% of the entire Rhine market (see Jonkeren et al., 2007).

[11] Van Geenhuizen et al. (1996) executed several in-depth interviews with shippers in the river Rhine area about how they adapt to situations of low and high water levels in the context of using inland waterway transport. They also mention that the transport price, for trips which pass Kaub, can maximally increase by 70% at extreme low water levels (water depth is between 181 and 190 cm at Kaub).

inland waterway transport on the river Rhine is inelastic.[12] It is estimated that in the period 1986–2004 there has been an annual average welfare loss of €28 million due to low water levels in the part of the river Rhine market considered. [13] The estimated loss in 2003 was as high as €91 million due to the very dry summer in that year.[14] Although these results are based on historical data they have clear implications for the inland waterway transport sector under climate change.

(RWS-RIZA *et al.*, 2005) estimated the costs of low water levels for domestic inland waterway transport in the Netherlands using a water management model. This model contains an economic tool which is based on assumptions about additional costs of low water levels. These extra costs concern the increase in the number of trips, in handling costs and costs as a result of longer waiting times in front of locks. The sum of these costs is called the annual expected value of the damage for inland waterway transport and is estimated to be equal to €72 million under current circumstances (climatic and economic). This expected value is based on the mean annual damage for a period of 100 years (1901 – 2000). In addition, for the year 2003, they found an expected damage of €111 million. The annual amount transported in the Dutch domestic market (100 million tonnes) is comparable to that of the Kaub-related market (80 million tonnes). (Royal Haskoning, 2007) use the same model, with the same assumptions about additional costs. They re-estimate the annual expected value of the damage for inland waterway transport under current circumstances to be equal to € 90 million.[15] They modify their previous results by taking into account the KNMI'06 climate scenarios and future economic growth scenarios. The results turn out to be very sensitive for the economic growth scenario which is used. The annual expected value of the damage for inland waterway transport in 2050 is €79 million in case of climate

[12] The price elasticity of demand is defined as the effect of a relative change in the price on a relative change in demand. An elasticity is called inelastic when its value is between -1 and 1 and elastic when its value is smaller than -1 or larger than 1.

[13] In (Jonkeren *et al.*, 2007), the annual welfare loss can be interpreted as the extra total amount of inland waterway transport costs that is paid for by shippers because of low water levels (in the geographical market under consideration).

[14] For many purposes, the 2003 event can be used as an analog of future summers in coming decades in climate impacts and policy studies (Beniston, 2004).

[15] The difference between the expected value of the damage (€72 and €90 million) in the two studies can be explained because of a difference in the period on which the mean value of the damage is based. In (RWS-RIZA *et al.*, 2005) this period is 100 years while in (Royal Haskoning, 2007) it is 7 years.

scenario W, and € 280 million in case of scenario W+. However, economic growth is not included in these estimations. If the economic scenario "global competition" is included, the expected values of the damage rise up to about €140 million and €670 million respectively. Finally, (Rothstein *et al.*, 2009) approach the low water level issue from the perspective of a bulk-cargo dependent shipper. They show the expenses of an exemplary power plant located at the upper Rhine as illustrated by Figure 2. In the year 2003, transport costs under real conditions were up to twice as high than expenses for optimal conditions for inland waterway transport.

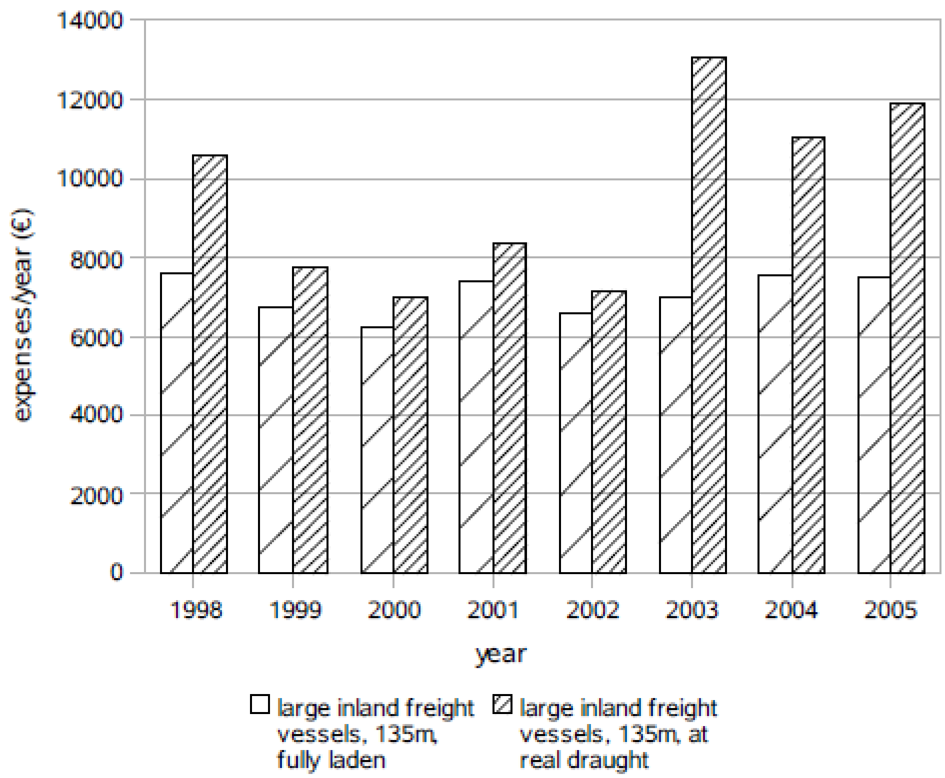

Figure 2: Transport costs of a power plant at the Upper Rhine for transport with 135m inland vessels assuming optimal water levels conditions (maximum draught) and real water level circumstances.

Source: (Rothstein *et al.*, 2009)

4 Reliability

Within a transport economics context, reliability can be defined as the degree to which deliveries arrive on time, i.e. the percentage on time arrivals of shipments in a certain time period (month, year). It is expected, that low and high water levels in waterways will result in an increase in the number of inland waterway deliveries that do *not* arrive on time (Radmiloviæ and B.Dragoviæ, 2007;Middelkoop and J.C.J.Kwadijk, 2001;DHV, 2008).

In case of high water levels, inland waterway transport may be stopped above a particular threshold water level, to prevent river dikes from breaking. This implies that inland ships are not able to navigate for a period of time (usually several days) and consequently they will arrive (way) behind schedule at their destination.

In the case of low water levels, ships are restricted in their load factor. Given inelastic demand for inland waterway transport, (Jonkeren *et al.*, 2007;2009), more trips will be made on the inland waterways in periods with low water levels. This may result in detours, longer waiting times in front of locks, one way traffic on some waterways, and more inland ships in ports that have to be (un)loaded. So, reliability of inland waterway transport will probably worsen due to low water levels.

4.1 Climate change and reliability of inland waterway transport

To our knowledge, studies that explicitly model the effect of low and high water levels on reliability of inland waterway transport are absent. (Harris, 1997) gives an indication for the increase in time that the river Rhine at Cologne is blocked due to future high water levels. He notes that by 2050, inland waterway transport may be impossible during 1.2% of the time in a year, against 0.8% in 1997. It remains unclear on which climate scenario this finding is based. He notes that in general the reliability will decrease in periods with low or high water levels.

(Quispel and J.A.Visser, 2007) examine the reliability of the waiting time for inland waterway carriers in front of four locks, in a particular part of the waterway network in the

Netherlands in the year 2040.[16] The water level is one of the explaining variables. More specifically, the daily water levels in the year 2004 were used, so the effect of low water levels in 2004 is incorporated into the analyses.[17] Other variables that are taken into account are economic growth (until 2040), (seasonality of) demand for inland waterway transport and (seasonality of) demand for recreational navigation. Reliability is defined as the dispersion of the waiting time per month. In the part of the Dutch inland waterway network assessed, low water level situations are specifically relevant as they determine route choice of the carriers: in the case of low water level most carriers will choose one particular link in the network under consideration implying longer waiting times and less reliable waiting times in front of locks located in that waterway link.[18] The authors find that, in the busiest month of the year (August), in the most extreme scenario for economic growth, for the lock that is most heavily affected, there is a 6.6% probability that a ship will have to wait more than 30 minutes in the year 2040. For shippers, this result suggests that 1 out of 15 ships will arrive more than 30 minutes later than scheduled. Note that the mentioned probability for delay applies to only one lock. On some routes, carriers are likely to pass more than one lock implying an accumulation of waiting time. Including the daily water levels which are representative for a year under future climate change (for example: the water levels in 2003, a year which is considered to be representative for a year in the W+ climate scenario (KNMI, 2006;Beniston, 2004)), would most likely lead to a higher percentage of ships waiting for more than 30 minutes, so the reported percentage is clearly an underestimate for future climate change conditions.

In additional simulations, several so called hindrance-scenarios are considered for inland waterway transport as well as recreational navigation. One of these scenarios concerns extreme low water levels, as they occurred in the year 2003. It is found that, by the year 2020, in the most extreme scenario for economic growth, for the lock that is most heavily affected, the mean waiting time increases by 23% compared to the basic scenario for 2020 (no extreme low water

[16] The part of the waterway network considered is the eastern part of the rivers Rhine and Meuse near the city of Nijmegen in the Netherlands.

[17] Note that daily water levels in the river Rhine in 2004 are comparable to water levels under current climate conditions. So, the results in Quispel and Visser (2007) do not incorporate the effect of low (and high) water levels under climate change.

[18] The carriers who are affected in their load factor will choose the link with the largest draught.

levels). A similar simulation was run for the recreational navigation sector for which they find an increase in mean waiting time of 11% (Quispel and J.A.Visser, 2007). To what extent this increase in waiting time in front of a lock decreases the reliability of the whole trip remains unexplained. The explanation for the smaller percentage for recreational navigation is that these ships are smaller. As a result they better fit into a lock together with other ships than large inland freight vessels.

In (HKV, 2007) a study was carried out to evaluate several alternative ways of enlargement of the fairway on a part of the river Rhine in the Netherlands. Its goal is to create a sustainable fairway with a guaranteed width and depth (a guaranteed reliability) in the long term. Climate change is expected to play a significant role as low flows make it more difficult to assure those dimensions of the waterway.

Closely related to reliability is the attribute safety. Safety can be defined as the probability that an inland ship will collide with another ship, a bridge or the river bank. This probability is likely to increase in periods with high water levels (increased river flow) and low water levels (a smaller fairway in combination with more trips). The above mentioned accidents may result in a blockage of the waterway affecting reliability. One study which mentions that extreme water levels influence safety and reliability of inland waterway transport is (Rothstein *et al.*, 2009).

We continue this literature review by focusing on studies that examine, among other factors, the importance of reliability for shippers of freight. Reliability is only one qualitative factor on which (inland waterway) freight shippers base their mode choice. They also value factors like service frequency, transit time, a carrier’s flexibility, the probability of damage and of course the quantitative factor transport costs. The knowledge on the importance of reliability is relevant in the light of this study: if shippers who make use of inland waterway transport do not bother about reliability at all, a deterioration of the reliability due to low and high water levels will not lead to adaptive behavior which might affect the competitive position of the port of Rotterdam.

4.2 The importance of reliability in freight transport

The importance of reliability can be expressed relative to other determinants of mode choice. Table 6 offers an overview of studies which examine reliability as one of the determinants of mode choice. Respondents in these studies are shippers or freight forwarders. Except for one study (Beuthe and Ch.Bouffioux, 2008) inland waterway transport is not considered as a possible transport mode for shippers and freight forwarders. So, little is currently known about how shippers that make use of inland waterway transport value reliability.

We will now elaborate on the studies in Table 6. From Shinghal and Fowkes (2002), it appears that exporters (via the port of Bombay) consider reliability to be very important, which is due to their need to ensure that the consignment arrives at the port in time for the ship. As the port of Rotterdam is also a major point for exporting, it is likely that reliability is also highly valued by shippers who use the port of Rotterdam for their exporting goods flow.

Shinghal and Fowkes (2002) and Danielis *et al.* (2005) both find that firms which organize their input flows on JIT principles have a high perceived value for reliability. Because transportation of containers on the river Rhine is also often organized according to JIT principles, reliability is likely to be important for the shippers who hire container carriers.

For relatively large firms, cost is more important than qualitative attributes like reliability (Danielis et al, 2005). As many production firms in the German industrial Ruhr area, which are located at the river banks of the Rhine, are very large, this finding suggests that reliability is not of primary importance for shippers that make use of inland waterway transport in this area.

Beuthe and Bouffioux (2008) show that reliability is more important on short distance transport and for road transport but does not play an important role for shippers that make use of inland waterway transport. The authors also estimate a monetary value for the reliability of inland waterway transport.[19] They find that for a 1% point increase in reliability of inland waterway transport, a shipper is willing to pay €0.0001 extra per tonne-kilometer. For a fully loaded inland ship of 2500 tonnes which makes a trip over 300 kilometers this value of reliability implies that a shipper is willing to pay €75 extra for a 1% point increase in reliability. In

[19] This is actually the only study which has calculated a value of reliability (VOR) for inland waterway transport.

comparison to rail and road the VOR is very low. For rail the VOR is estimated to be €0.0004 and for road €0.0130. This is an important finding in the context of the current study. It suggests that customers of transport services that consider reliability as important tend to exclude inland waterway transport from their choice set. An explanation may be that these are also the customers that attach a high importance to speed. This conjecture is confirmed by the results on the estimations on the value of time in (Beuthe and Ch.Bouffioux, 2008).

Table 6: Recent studies which examine importance of reliability

Study	**Geographical context**	**Transport modes**	**Importance reliability**
(Shinghal and T.Fowkes, 2002)	India, Delhi – Bombay corridor.	Road, rail	Very important for exporters (transshipment in port) and autoparts sector (JIT). Attributes: cost, time, reliability, frequency.
(Danielis *et al.*, 2005)	Italy, north-east and centre	Road , rail	Reliability and risk of damage most important out of 4 attributes (cost, time, reliability, damage).
(García-Menéndez *et al.*, 2004)	Spain, east	Road, sea	Reliability and damage least important out of 5 attributes (cost, time, reliability, damage, frequency).
(Bergantino and S.Bolis, 2005)	Italy, north-west	Road, sea	Frequency (1) and reliability (2) most important out of 4 attributes (cost, time, reliability, frequency).
(Beuthe and Ch.Bouffioux, 2008)	Belgium	Road, rail, inland waterways, sea	Reliability third most important attribute (after cost and time) out of 6 attributes. For inland waterway shippers reliability is ranked fourth.

In addition to the studies in Table 6, we mention Kouwenhoven et al. (2005). They focus on the attribute of reliability, one of their results being Table 7. Compared with the other transport modes, reliability is valued lowest by shippers that make use of inland waterway transport (although the differences are small). Still, about two thirds of these shippers expect their shipments to arrive on a specific moment or within a time frame around this moment.

Table 7: Percentage of freight transport trips for which arriving on time is of importance

	Road	Rail	Inland waterways	Sea	Air
Point of time or time frame	64.4%	77.8%	64.2%	65.4%	68.7%
On time is not important	35.6%	22.2%	35.8%	34.6%	31.3%

Source: Kouwenhoven et al. (2005).

Finally, (I&O Research, 2009) address reliability in their study on the satisfaction of Dutch shippers that make use of inland waterway transport (domestic and border crossing). They find that 31% of all shippers judge inland waterway transport to be less reliable than road transport and 22% has the opposite opinion. Compared to rail transport, inland waterway carriers are judged to be less reliable by 7% and more reliable by 20% of the respondents (see Table 8).

Table 8: Reliability of inland waterways compared with competing modes

	Inland waterways more reliable	Inland waterway less reliable
Road	22%	31%
Rail	20%	7%

Source: (I&O Research, 2009)

On average, a delay of 13% of the original travel time is still acceptable.[20] For 10% of all shippers not any delay is acceptable and for 23% more than 10% delay of the original travel time is still acceptable. The most mentioned causes for delays are waiting time at bridges and locks, delay during (un)loading at terminals and weather circumstances (I&O Research, 2009).[21]

From the review above it turns out that in the literature there is no consensus on the importance of reliability for shippers (who make use of inland waterway transport) in determining mode choice. As some studies indicate that reliability is of importance for shippers and because studies in which inland waterway transport is a mode under consideration hardly

[20] A barge trip usually takes at least one day. 13% of 24 hours or more implies that extra waiting time in front of locks of 30 minutes, as found by Visser and Quispel (2007), is not a big issue.

[21] Note that extreme weather circumstances are expected to occur more often in the future due to climate change.

exist, further research on the importance of reliability for shippers that use inland waterway transport is recommended.

5 Modal share

For years, the transport policy of the European Commission is aiming to establish a structural modal shift from road transport to railways and inland waterways, in order to reduce the emission of greenhouse gasses, because road transport is generally considered to be more polluting than its competing transport modes (European Communities, 2006). The desired shift in modal split is then likely to contribute to the mitigation of climate change.

In this section however, we will focus on the reverse relationship: what is the effect of climate change on modal split? In the previous sections, it was observed that inland waterway transport prices increase as the water level decreases. In addition, the reliability of inland waterway transport is likely to deteriorate due to low and high water levels. One possible consequence of these changes in transport prices and reliability is a deterioration of the competitive position of inland waterway transport compared with rail and road transport, and thus a change in modal split. (Jonkeren *et al.*, 2009) study this issue using a GIS-based software model called NODUS which provides a tool for the detailed analysis of freight transportation over extensive multimodal networks. They assess the effect of low water levels on the costs of transport operations for inland waterway transport, and consequently on its modal share, in the Kaub-related Rhine market, under several climate scenarios. The reliability aspect is ignored. It turns out, that the effect of the higher transport costs on the modal split is limited. Under the most extreme KNMI'06 climate scenario (W+), inland waterway transport would lose about 5.4% of the quantity that is currently being transported annually in the part of the Rhine market considered. About 70% of these tonnes are shifted to road, the remaining part to rail. Generalizing the loss of cargo to a larger geographical area, maximally 16 million tonnes are transferred to competing modes in the *total* Rhine market under current economic conditions. Some limitations of the model are that it is assumed that shippers do not have switching costs when choosing for another transport mode, that no technological improvements will be made on the supply side (infrastructure and fleet) and that future demand is equal to current demand.

Table 9 was retrieved from (Bfg, 2006). It depicts the transported volumes on German inland waterways in the year 2003, compared to those of 2002. The authors mention that the majority of the total decrease of 5.1% can be attributed to low water levels as the year 2003 was an extreme year in terms of low water levels. Furthermore, they note that in the years after 2003, inland waterway transport won back the tonnes lost in 2003 on the competing modes. (DHV, 2008) also mentions the risk of losing cargo to other modes.

Table 9: Freight transport on German inland waterways in thousands of tonnes.

Type of traffic	**2002**	**2003**	**Change (%)**
Domestic	55,844	53,419	-4.3
Border crossing	150,922	145,111	-3.9
Transit	24,981	21,469	-14.1
Total	231,746	219,999	-5.1

Source: (Bfg, 2006)

From an interview carried out by (Nomden and W.van Deursen, 1999), it appears that shippers of dry bulk cargo will not choose for competing transport modes due to increases in transport costs and costs from higher stocks. As main reason the fact that transport by inland waterways is considered to be about 50% cheaper than transport by competing modes by the shipper, is mentioned. Note that this information is retrieved from only one interview ten years ago.

6 Conclusion

In this report we have gathered and structured the literature on the effects of high and low water levels in inland waterways on costs, reliability and modal share of inland waterway transport. Knowledge on this type of literature is relevant for the Port of Rotterdam because much cargo is transported from this sea-port to the hinterland by inland waterways. Several studies have examined the effect of climate change on costs of inland waterway transport. However, much less literature is available on the effect of climate change on reliability and modal share of this transport mode.

With respect to the effect on transport costs different results are found. This difference in results can mainly be explained by the wide variety in climate- and- economic scenarios that are used in the different studies. In the North American literature Millerd (2005), finds an average increase in annual transport costs of 13% for 2050 for navigation in the Great Lakes river system as a result of low water levels compared to current annual transport costs. A study for the Middle Mississippi River reports an increase in annual transport costs of 35% due to low *and* high water levels in one climate scenario and a *decrease* of 44% in another climate scenario for the year 2100 (Olsen *et al.*, 2005). In the European literature (Jonkeren *et al.*, 2007) estimates an increase in annual transport costs due to low water levels on the river Rhine of about 15% in a year which is more or less representative for the most extreme KNMI'06 climate scenario for 2050 (W+). From (Royal Haskoning, 2007) it turns out that the extent to which economic growth will occur has a significant impact on the increase in transport costs due to low water levels. Annual transport costs due to low water levels will increase by 9% in the case of climate scenario W+ and current economic circumstances while the cost increase will amount to about 23% in the case of climate scenario W+ in combination with the economic scenario Global Competition (Centraal Planbureau *et al.*, 2006).

As not much literature on the effect of high and low water levels on reliability of inland waterway transport exists, we focused on the importance on the attribute reliability for shippers of freight. Especially (Beuthe and Ch.Bouffioux, 2008) present interesting results in this context. They show that reliability is more important on short distance transport and for road transport but does not play an important role for shippers that make use of inland waterway transport. This conjecture is confirmed by the estimated monetary value for the reliability of inland waterway transport. The authors find that for a 1% point increase in reliability of inland waterway transport, a shipper is willing to pay €0.0001 extra per tonne-kilometer. Compared with the value of reliability (VOR) of other modes this is small. For a fully loaded inland ship of 2500 tonnes which makes a trip over 300 kilometers this value of reliability implies that a shipper is willing to pay €75 extra for a 1% point increase in reliability. This is an important finding in the context of the current study. It suggests that customers of transport services that consider reliability as an important issue tend to exclude inland waterway transport from their choice set. An explanation may be that these are also the customers that attach a high importance to speed. Although

(Beuthe and Ch.Bouffioux, 2008) suggest that reliability is not an important attribute for shippers that make use of inland waterway transport, some other studies indicate the opposite. For example, (Kouwenhoven *et al.*, 2005) mention that for 64% of the shippers that make use of inland waterway transport, arriving on time or within a time frame is important. For other transport modes they show similar percentages. In addition, (I&O Research, 2009) find that for 77% of the shippers in their survey (n = 150), a delay of more than 10% of the planned travel time is not acceptable. Because of the lack of knowledge on the effect of climate change on reliability in inland waterway transport and because of the contradictory results in the existing literature further research on the reliability issue is recommended.

Finally, the effect of climate change on the share of inland waterway transport in the model split was assessed. If high and low water levels negatively affect transport costs and reliability, it is likely that a part of the cargo that is originally transported by inland waterways will be shifted to competing modes. One particular study that specifically analysed the effect of higher transport costs (due to low water levels) on modal split is (Jonkeren *et al.*, 2009). Their results indicate that under the most extreme KNMI’06 climate scenario, inland waterway transport on the Rhine will lose 5.4% of the annual quantity that is currently being transported. Strikingly, (Bfg, 2006) also find a decrease of 5%. However, this figure applies to the difference in quantity transported by inland waterway on German waterways between the years 2003 and 2002. They state that this reduction in tonnes transported can be attributed to the extreme low water level situation in 2003 although they do not show that the causal relationship is really present.

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Nederlandse samenvatting

In dit rapport hebben we de literatuur over de effecten van hoge en lage waterstanden in waterwegen op de kosten, betrouwbaarheid en modal share van de binnenvaart verzameld en gestructureerd. Kennis over dit onderwerp is relevant voor de haven van Rotterdam omdat veel vracht over de binnenwateren wordt vervoerd tussen deze zeehaven en het achterland in (voornamelijk) Duitsland. Ongeveer 50% van alle bilaterale handel (gemeten in tonnen) tussen Nederland en Duitsland gaat per binnenvaartschip. Verschillende studies hebben het effect van klimaatverandering op de transportkosten in de binnenvaart onderzocht. Er is echter veel minder literatuur beschikbaar over het effect van klimaatverandering op (1) de betrouwbaarheid en (2) het aandeel in de modal split van deze transportmodaliteit.

Met betrekking tot het effect op de kosten van binnenvaartvervoer zijn in de literatuur verschillende resultaten gevonden. Dit verschil in resultaten kan voornamelijk worden verklaard door de grote verscheidenheid aan klimaat- en economische scenario's die gebruikt worden in de verschillende studies. In de Noord-Amerikaanse literatuur vindt Millerd (2005) een gemiddelde stijging van de jaarlijkse kosten van vervoer van 13% voor 2050 voor de scheepvaart in de Great Lakes river systeem als gevolg van lage waterstanden ten opzichte van de huidige jaarlijkse kosten. Een studie voor het middengedeelte van de Mississippi rivier meldt een stijging van de jaarlijkse transportkosten van 35% als gevolg van lage *en hoge* waterstanden in het ene klimaat scenario en een daling van deze kosten van 44% in een ander klimaat scenario voor het jaar 2100 (Olsen et al., 2005). In de Europese literatuur schat Jonkeren et al. (2007) een stijging van de jaarlijkse kosten van vervoer per binnenvaartschip op de Rijn als gevolg van lage waterstanden van ongeveer 15% in een jaar dat min of meer representatief is voor het meest extreme KNMI'06 klimaat scenario voor 2050 (W+). Uit een studie van RWS-RIZA (2007) blijkt dat de mate waarin economische groei zal optreden een aanzienlijke invloed heeft op de stijging van de transportkosten als gevolg van lage waterstanden. De jaarlijkse kosten van vervoer per binnenvaart zullen als gevolg van de lage waterstanden met 9% stijgen in het geval van het klimaatscenario W+ in combinatie met de huidige economische omstandigheden. De stijging van de transportkosten zullen daarentegen ongeveer 23% bedragen in het geval het klimaat scenario

W+ optreedt in combinatie met het economische scenario Global Competition (Centraal Planbureau et al., 2006).

Aangezien er niet veel literatuur over het effect van hoge en lage waterstanden op de betrouwbaarheid van de binnenvaart bestaat, hebben we ons gericht op het belang van het attribuut betrouwbaarheid voor verladers van vracht. Vooral Beuthe en Bouffioux (2008) laten interessante resultaten zien in deze context. Ze tonen aan dat betrouwbaarheid belangrijker is voor transport over korte afstanden (ten opzichte van vervoer over lange afstanden) en voor het wegvervoer (ten opzichte van andere modaliteiten). Voor verladers die gebruik maken van de binnenvaart wordt betrouwbaarheid als minder belangrijk beschouwd. Deze bevinding wordt bevestigd door de geschatte monetaire waarde voor betrouwbaarheid van binnenvaarttransport. De auteurs vinden dat voor een 1%-punt stijging van de betrouwbaarheid van de binnenvaart, een verlader bereid is € 0,0001 extra per ton-kilometer te betalen. In vergelijking met de waardering van betrouwbaarheid voor andere modaliteiten is dit laag. Voor een reis met een volledig beladen binnenvaartschip van 2500 ton over 300 kilometer impliceert de hierboven vermelde monetaire waarde van betrouwbaarheid dat een verlader bereid is € 75 extra te betalen voor een 1%-punt stijging van de betrouwbaarheid. Dit is een belangrijke vaststelling in de context van de huidige studie. Het suggereert dat de klanten van vervoersdiensten die betrouwbaarheid als een belangrijke kwestie beschouwen, de neiging hebben om de binnenvaart uit te sluiten van hun keuzeset. Een verklaring kan zijn dat dit ook de klanten zijn die een groot belang hechten aan snelheid. Hoewel Beuthe en Bouffioux (2008) suggereren dat de betrouwbaarheid niet een belangrijk kenmerk is voor verladers die gebruik maken van de binnenvaart, blijkt uit een aantal andere studies het tegenovergestelde. Bijvoorbeeld, Kouwenhoven et al. (2005) vermelden dat voor 64% van de verladers die gebruik maken van de binnenvaart, de aankomst van goederen op een bepaald tijdstip of binnen een tijdsbestek belangrijk is. Voor andere vormen van vervoer tonen ze soortgelijke percentages. Bovendien, vindt I & O Research (2009) dat voor 77% van de verladers in hun onderzoek (n = 150), een vertraging van meer dan 10% van de geplande reistijd niet aanvaardbaar is.

Vanwege het gebrek aan kennis over het effect van klimaatverandering op de betrouwbaarheid van de binnenvaart en vanwege de tegenstrijdige resultaten in de bestaande literatuur is aanvullend onderzoek naar de betrouwbaarheid van vervoer per binnenvaart (in relatie tot klimaatverandering) aanbevolen.

Tenslotte is gefocus op het effect van klimaatverandering op het aandeel van de binnenvaart in de modal split. Indien hoge en lage waterstanden een negatieve invloed op de kosten en betrouwbaarheid van binnenvaartvervoer hebben, is het waarschijnlijk dat een deel van de lading die oorspronkelijk door de binnenvaart werd vervoerd zal worden verschoven naar concurrerende vervoerswijzen. Een studie die specifiek het effect van hogere transportkosten (als gevolg van lage waterstanden) op de modal split onderzocht heeft is Jonkeren et al. (2009). Hun resultaten geven aan dat onder het meest extreme KNMI'06 klimaat scenario, de binnenvaart op de Rijn 5,4% van de jaarlijkse hoeveelheid vracht die momenteel wordt vervoerd zal verliezen. Opvallend is dat BfG (2006) ook een daling van 5% vindt. Dit percentage heeft betrekking op het verschil in hoeveelheid vervoerd door de binnenvaart op de Duitse waterwegen tussen de jaren 2003 en 2002 (in 2003 5% minder dan in 2002). Zij stellen dat deze vermindering van het aantal vervoerde tonnen kan worden toegeschreven aan de extreem lange periode van lage waterstanden in de Europese vaarwegen in 2003. Echter, het gesuggereerde causale verband wordt niet aangetoond.